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16. Abstract

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Analysis of the Benefits of Bulk Pre-Wetting Solid NaCl with Several Different Liquids

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For

Michigan Department of Transportation
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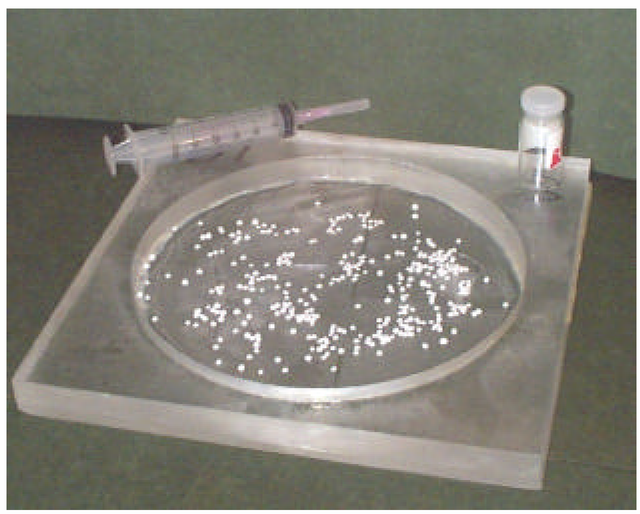

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Introduction

The use of de-icing and anti-icing chemicals on roadways is a proven and effective manner in which to combat the problem of hazardous winter driving conditions. However, chemical costs can be quite high, as are the costs of damage to the transportation system infrastructure and to the environment. The practice of pre-wetting solid deicers with a liquid provides several benefits. First, an increased snow and ice melting ability may be seen, due to the combination of chemicals being used. Because solid deicers must begin to dissolve in order to have an ice-melting ability, another benefit might be accelerated melting action, due to the small amount of solution already formed before application to the road. Finally, an ability to stick to the pavement, preventing bouncing of deicer crystals, would reduce loss of the chemical from the roadway, allowing for a lighter application rate. These benefits not only save money on de-icing chemicals, but reduce chemical runoff to the environment, as well as reduce corrosion to vehicles and infrastructure and may decrease the overall cost of winter road maintenance

The purpose of this project was to study the pre-wetting characteristics of several liquid de-icing chemicals using a standard laboratory melting test and solid NaCl (rock salt) Liquid volume applied was also used as a variable to start to determine what rates might be best for use in the field. Application rates of 6, 8 and 10 gallons/ton were compared at temperatures of 15°F, 20°F and 25°F.

Test Method

For all tests performed, either standard SHRP H-205.1, Test Method for Ice Melting of Solid Deicing Chemicals, or standard SHRP H-205.2, Test Method for Ice Melting of Liquid Deicing Chemicals was used. The method for this testing can be found in the Strategic Highway Research Program, National Research Council, publication designated SHRP-H-332. This is the Handbook of Test Methods for Evaluating Chemical Deicers. This test is designed to assess the total volume of ice that can be melted by an applied amount of deicer. Note that the test protocols utilize metric units.

Figure 1 is a photograph of the test apparatus used for ice melting. In general, an ice sample is created in a standard Plexiglas© dish. After application of a specified amount of chemical, the amount of brine created (mix of chemical and melt water) is recorded at time intervals up to 60 minutes. This testing was performed at three different temperatures: 15°, 20°, and 25° F. The results are given in tabular and graphical form as milliliters of brine collected per gram of deicer applied, which can be seen in the data section. The approximate amount of deicer applied for each test was 4.17 grams of solid NaCl, plus the appropriate amount of pre-wetting agent. At each temperature, three repetitions of the ice-melting test were completed for each of the five chemical combinations. The results from each temperature were averaged, thus giving a single melting performance amount for each temperature.

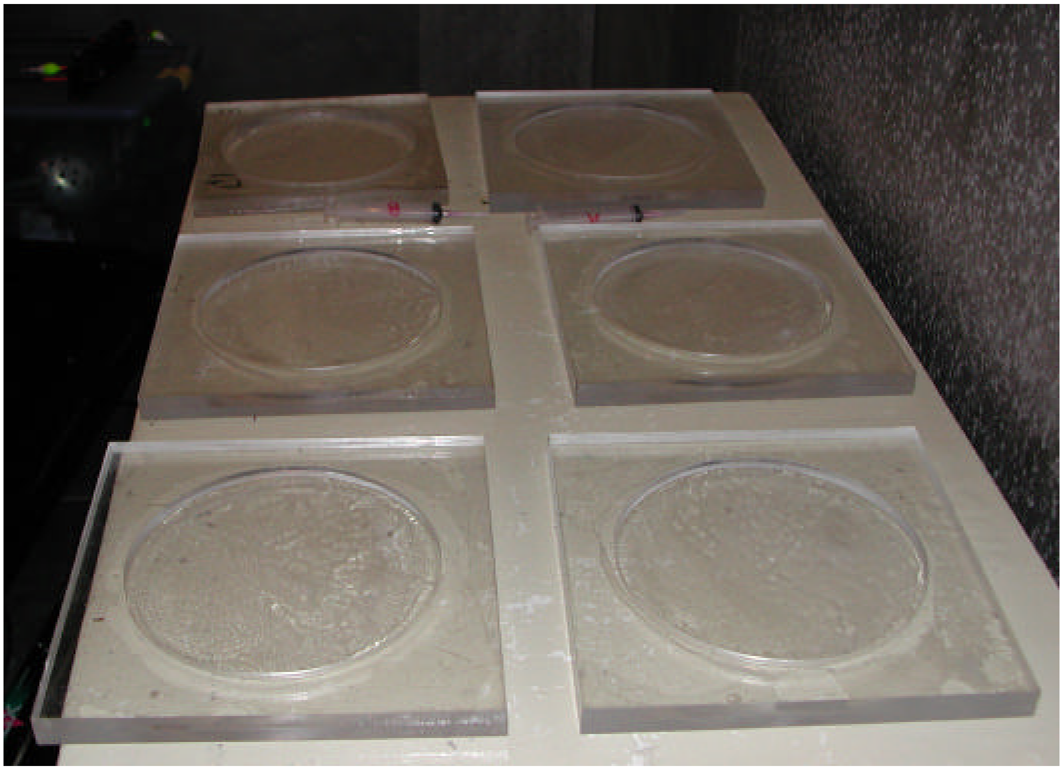

Figure 1: Ice Melting Test Apparatus

Initial Salt Crystal Size Analysis

Melt tests were performed to assess the melting potential of various size ranges of solid NaCl. Since a direct comparison is to be made between varied liquid application rates for this testing, a specific size range of particles is used to eliminate the variability of particle size.

The first task completed was to sieve rock salt into the following six size ranges:

>5/16 in
¼ in to 5/16 in
3/16 in to ¼ in
3/32 in to 3/16 in
.0787 in to 3/32 in
.0331 in to .0787 in

U.S. Standard sieve sizes for this grain separation are 5/16 in, ¼ in, No. 4 (3/16 in), No. 8 (3/32 in), No. 10 (0.0787 in), and No. 20 (0.0331 in).

The salt used for these tests was Morton Rock Salt for Making Ice Cream. This salt was used because it is essentially pure and doesn't contain the impurities of road salt.

For testing such as this, it is best not to include pellets of chemical with unknown make-up, such as is found in large salt piles. Samples of Morton non-iodized table salt were also tested, for a test of consistent "small" particle size. This salt was used to simulate the powdered size portion of bulk road salt.

Ten sets of three tests of each size range were run at 25°F, using the specified sample size of 4.17 grams. One set of three tests was run for a sample size of 8.34 grams, or twice the standard amount, as a sensitivity analysis on the effect of sample size for brine produced from a specific volume of ice.

From Figure 2, it can be seen that melting capacity increased with decreasing crystal size among the five largest crystal sizes, but then dropped off as the crystals became even smaller. This can be explained by the relative amount of surface energy of the various crystal sizes, combined with the number of crystals found in a 4.17 gram sample. For the largest crystals, typically only four or five actual pieces of salt made up the sample. These large pieces would require more time to dissolve into solution and provide less surface area contacting the ice than an equal quantity of smaller pieces. At the other end of the scale, the table salt would go into solution almost immediately, thereby depleting its ice melting capacity much more quickly. Ultimately, the 3/32 to 3/16 in crystal size was selected based on the results of this preliminary testing. This size range also compared visually to a good match to that average particle size of road salt.

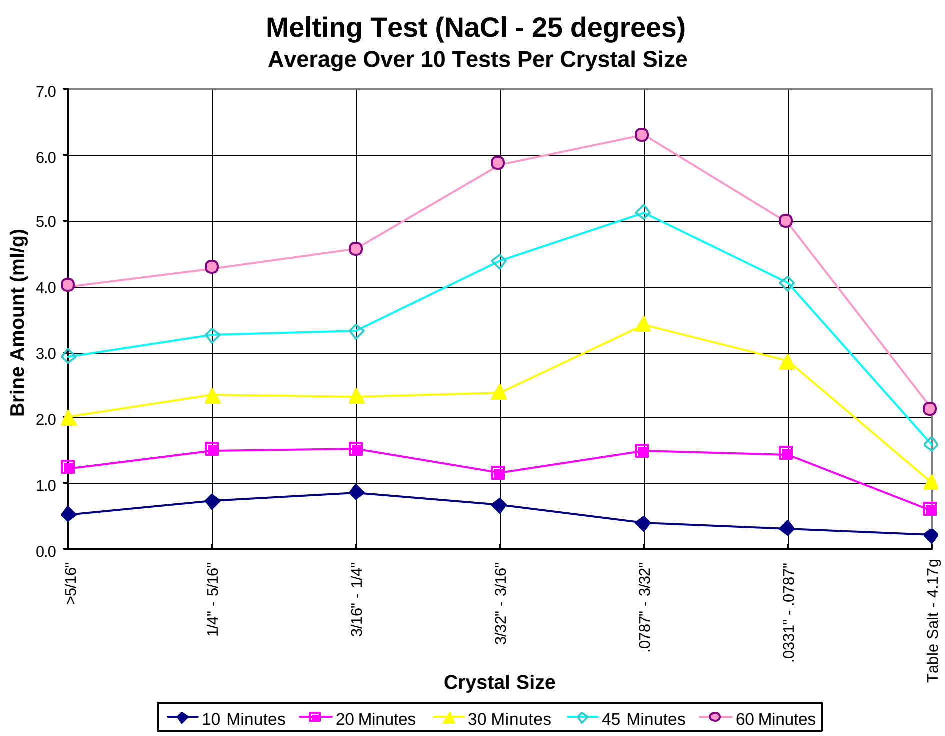

Figure 2: 25°F Dry NaCl Crystal Size Comparison

As shown in Figure 3, it was determined that the sample weight had little effect on the quantity of brine produced from a specific surface area of ice and weight of chemical. Since the SHRP protocol specifies the use of 4.17 gram samples, testing of the larger samples was discontinued.

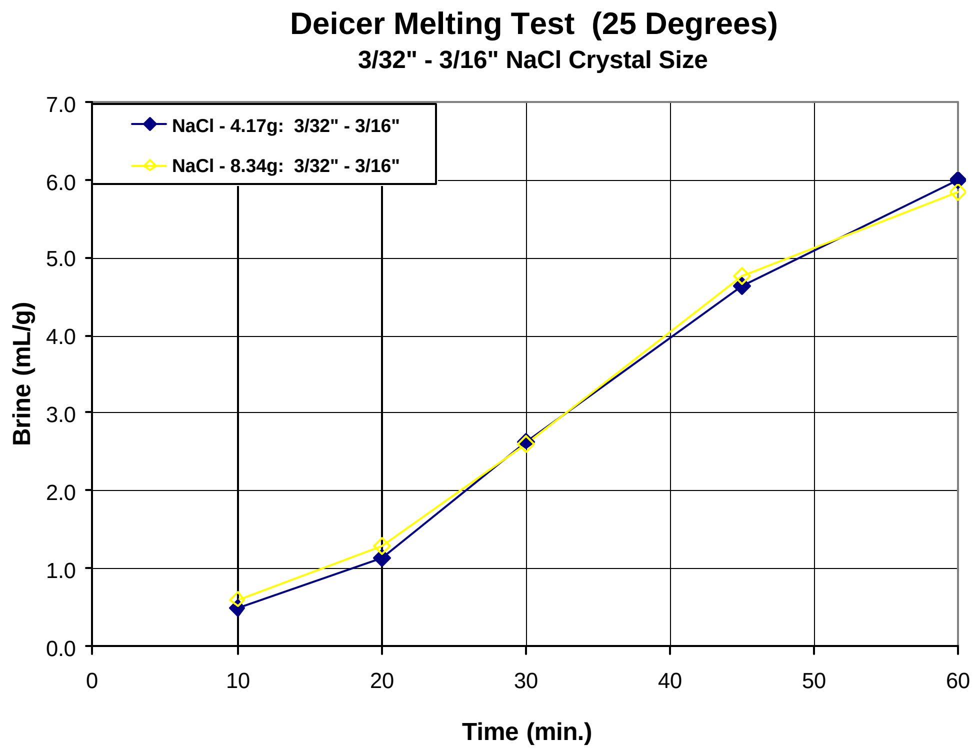

Figure 3: 25°F Dry NaCl Sample Weight Comparison

Initial Testing of Liquid Chemicals

Samples of five chemicals were obtained from the manufacturers, with the accompanying MSDS information. These chemicals were as follows:

A: Corguard AG30, manufactured by General Chemical
B: ClearLane Liquid, Cargill
C: Caliber M1000 AP – Anti-Icing & De-Icing Agent, Envirotech Services, Inc.
D: De-Ice NB Anti-Icing Fluid / Liquid Deicer, Road Solutions, Inc.
E: De-Ice 55 Anti-Icing Fluid / Liquid Deicer, Road Solutions, Inc.

Melting tests were performed on the liquid samples. A set of five tests on each of the five chemicals was performed at 15°F, 20°F, and 25°F. The results appear in Figures 4 through 6.

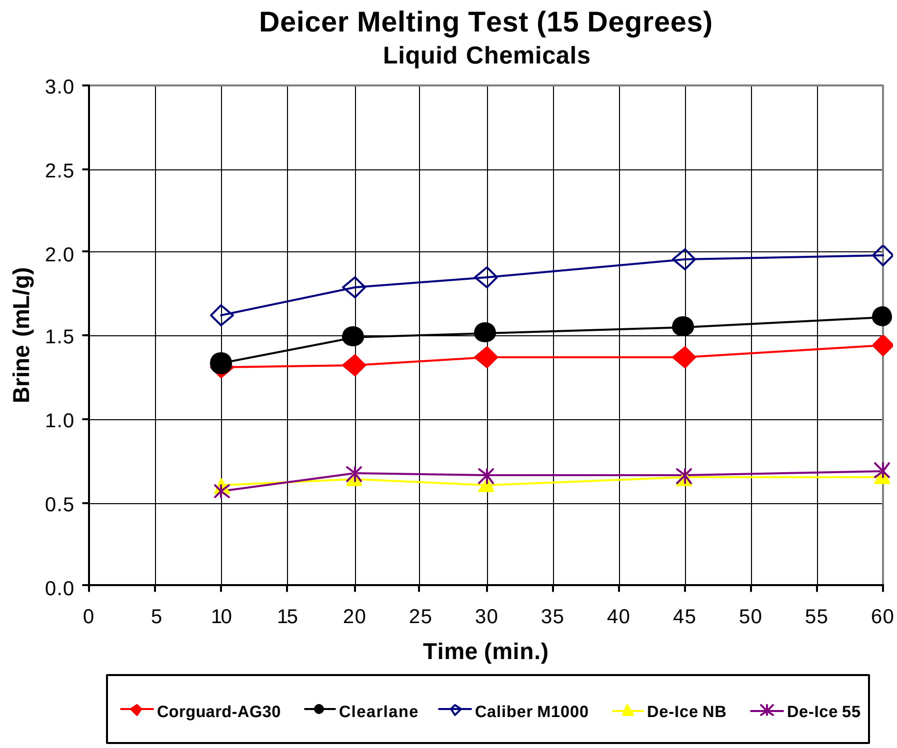

Figure 4: 15°F Liquid Chemical Melting Test

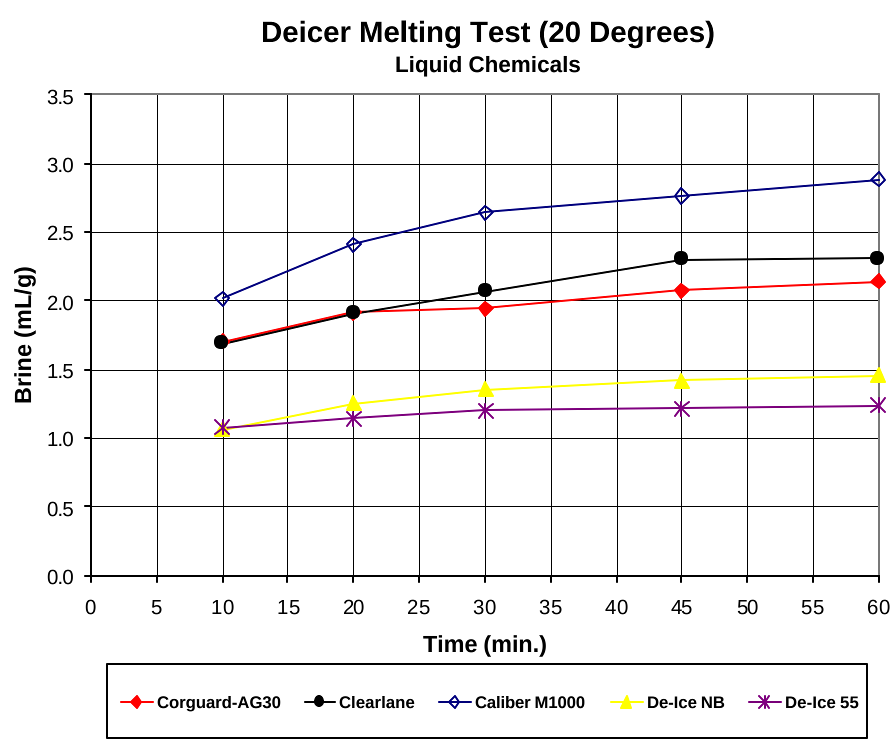

Figure 5: 20°F Liquid Chemical Melting Test

At 15°F and 20°F, the Caliber M1000 produced a larger amount of brine per weight of chemical than did the other products. The De-Ice NB and De-Ice 55 produced the smallest amount in these tests. The Caliber product is slightly better as a pure melter at 25°F than the other four, with NaCl, Clearlane, and Corgaurd all very comparable to each other, and the two De-Ice products producing the least brine. Overall, it does not appear that there is much further melting of ice by the brine after the first measurement is taken, and the brine is re-deposited on the surface of the sample. However, some of these chemicals are not intended for direct application as a deicer, but rather as pre-wetting agents. This information does help to clarify potential differences between the performance of the respective wetted NaCl testing.

Figure 6 contains results of melting tests at 25° F for each of the six liquids as received from the manufacturers. This result is consistent with the tests at the colder temperatures. Since these products are not all developed to be used in their pure state, care should be taken when comparing, but in general, this is a good way to rank effectiveness. The fact that the relative effectiveness at the three different temperatures is the same for all of the chemicals enforces the validity of the results. The main point to be made here, is that there is not much difference in melting ability between at least the top 4 chemicals. This is even more important, when the small amounts used for pre-wetting are taken into consideration. Also, at these warm temperatures, water creating NaCl brine is close to being as effective or better than the other five.

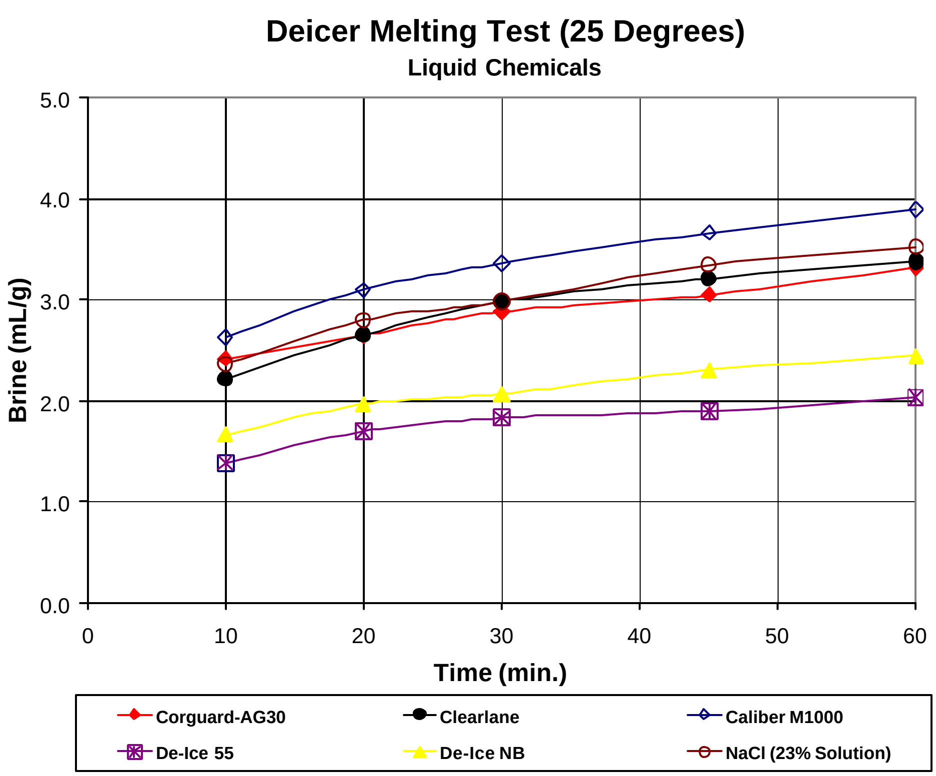

Figure 6: 25°F Liquid Chemical Melting Test

In each test of the liquid chemicals, foaming of the measured brine was seen as a problem. With several of the chemicals, enough foam formed as the brine was drawn into the syringe and expelled back out again as to make accurate measurements very difficult. Also, some of the chemicals showed a tendency to separate or settle over time. The following was observed:

Sample A – Corguard AG30: A lot of foaming is created as the brine is drawn into the syringe, making it difficult to obtain an accurate reading of the brine volume during each test. The chemical visibly separates over time into two distinct layers in the sample bottle. These layers are easily remixed.

Sample B – ClearLane: A similar amount of foaming as in Sample A is seen, although the foaming of the ClearLane brine seems to diminish with each reading during a test, as the chemical becomes more diluted with melt water. The chemical settles out over time, leaving a sludgy layer in the bottom of the bottle. This thick layer mixes back into solution fairly easily.

Sample C – Caliber M1000: No foam. A little settling occurs, leaving a thin layer of precipitate which is easily mixed back in.

Sample D – De-Ice NB: Extreme foaming. Foam forms as the chemical sample is drawn into the syringe. Brine foams with each reading over time, and also foams as brine is expelled from the syringe. Some foam remains floating on ice/brine sample surface, and does not dissipate. It is very difficult to obtain an accurate measurement of the brine. Also, if the chemical sample bottle is shaken, the foam quickly fills all available space in the bottle, and it takes considerable time for the foam to dissipate. Some residual foam remains floating on the surface of the liquid indefinitely. No apparent separation or settling of the chemical is observed.

Sample E – De-Ice 55: Extreme foaming. Foams as chemical sample is drawn, as above. Continues to foam with each test reading over time, and some of the foam also remains part of the brine. No apparent separation or settling of the chemical was observed.

Testing of Pre-Wetted NaCl at 15°, 20° & 25° F

After the preliminary testing was completed, samples were made up consisting of solid NaCl, sieved to a size range of 3/32 in to 3/16 in, and pre-wetted by the previously mentioned liquids at 6, 8 and 10 gallon/ton rates. Calculations were done to determine the weight of chemical needed to pre-wet 2000 lbs. of NaCl at each rate, and the samples were mixed to obtain the desired amount of each formula.
Several methods of sample preparation were tested to determine which would provide the most accurate samples. One method tried was to first measure out a single, 4.17 gram NaCl sample into a Petri dish, and to apply the measured liquid amount to that, from a syringe. The mixed sample was then transferred to a small sample bottle, to

minimize evaporation of the liquid. The main problem with this was that some of the liquid would remain on the surface of the dish, and then an additional amount would cling to the walls of the sample bottle. It was not possible to obtain an accurate measurement of the liquid chemical that actually was applied to the ice for testing.

The method that was determined to be the most accurate for our tests was to first measure out a sample of NaCl large enough from which to draw all of the smaller test samples for that chemical mixture. In most cases, that initial sample was the equivalent of 15 to 20 samples of 4.17 grams. The dry NaCl was spooned into a large wide-mouthed Nalgene bottle. Next, the liquid chemical was carefully measured and applied by syringe to the salt in the bottle, using a digital balance to ensure the application of the correct amount of chemical. Each bottle was then sealed and stored upside-down in order to keep the liquid from draining to the bottom of the bottle and sticking. Each time an individual sample was drawn, the bulk sample bottle was turned right-side-up and mixed vigorously, in an attempt to keep the mixture as uniform as possible, and to try to minimize the amount of chemical clinging to the walls of the bottle.

The actual pre-wetting rates were calculated using the carefully measured weights of the salt and the liquids. Table 1 identifies the liquid chemical, the specific gravity of that chemical, the sample I.D. used, the target pre-wetting rate, the total number of samples mixed per bottle, the weights of the solid NaCl and liquid used, and the calculated application rate.

Table 1: Summary of Pre-wetting Chemical Application

Chemical	S.G.	Sample	Rate	No. of Samples	g NaCl	g Liquid	Actual Rate (gal/ton)
Corguard AG30	1.24	A1	6 gal/ton	21.4	89.4891	2.7806	6.0052
		A2	8 gal/ton	16	67.0952	2.7911	8.0398
		A3	10 gal/ton	19.3	80.5012	4.1639	9.9968
ClearLane	1.32	B1	6 gal/ton	19.2	79.8821	2.6484	6.0193
		B2	8 gal/ton	21.6	89.8717	3.9638	8.0075
		B3	10 gal/ton	17.2	71.902	3.9603	9.9999
Caliber M1000	1.27	C1	6 gal/ton	19.2	79.8845	2.5574	6.0411
		C2	8 gal/ton	21.6	89.8707	3.8196	8.0201
		C3	10 gal/ton	17.2	71.8989	3.8204	10.0269
De-Ice NB	1.22	D1	6 gal/ton	19.2	79.887	2.5244	6.2073
		D2	8 gal/ton	21.6	89.8627	3.6759	8.0354
		D3	10 gal/ton	17.2	71.892	3.6622	10.0065
De-Ice 55	1.275	E1	6 gal/ton	19.2	79.8883	2.558	6.0185
		E2	8 gal/ton	21.6	89.8755	3.8303	8.0106
		E3	10 gal/ton	17.2	71.8919	3.8366	10.0309

Before individual samples were measured from the bulk samples, small wide-mouthed Nalgene bottles were labeled and weighed, in order to obtain a tare weight. The bottles were filled as accurately as possible, re-weighed, and placed in the cold room. After a minimum of one hour had passed, and the sample bottles had acclimated to the cold room conditions, a set of five ice samples had pre-wetted NaCl applied, with an additional control sample treated with dry NaCl. Brine measurements were taken at 10, 20, 30, 45 and 60 minutes from the time that the deicer was applied. The empty bottles were returned to the lab area, and allowed to re-acclimate before being re-weighed to determine the liquid residue remaining in the bottle. From the net amount of deicer used, a more accurate pre-wetting rate was obtained for each sample. Overall, there was a definite difference among the pre-wetting chemicals, some of which tended to leave more residue than others. The Caliber M1000 appears to have left the least residue, averaging 9.7% overall, while the others ranged from 14.1% for De-Ice 55 to 17.2% for Corguard. Table 2 shows the average resulting pre-wetting rate for each chemical used for each test condition.

Table 2: Residual Chemical Amounts for Each Chemical and Application Rate

Chemical	Temp (F)	6 Gal/Ton			8 Gal/Ton			10 Gal/Ton	
		Avg. Rate (Gal/Ton)	Residue (Gal/Ton)	% Residue	Avg. Rate (Gal/Ton)	Residue (Gal/Ton)	% Residue	Avg. Rate (Gal/Ton)	Residue (Gal
Corguard AG30	15	4.89	1.11	19%	6.56	1.48	18%	8.34	1.65
	20	5.16	0.84	14%	6.81	1.23	15%	8.03	1.96
	25	4.97	1.04	17%	6.89	1.15	14%	7.88	2.12
Clearlane	15	4.92	1.10	18%	6.65	1.36	17%	8.41	1.59
	20	5.31	0.70	12%	6.91	1.10	14%	8.46	1.54
	25	5.02	1.00	17%	6.92	1.09	14%	8.05	1.95
Caliber M1000	15	5.20	0.84	14%	7.23	0.79	10%	9.09	0.93
	20	5.56	0.48	8%	7.12	0.90	11%	9.09	0.93
	25	5.62	0.42	7%	7.37	0.65	8%	8.93	1.09
De-Ice NB	15	5.12	1.09	18%	6.77	1.26	16%	8.40	1.61
	20	5.42	0.79	13%	7.04	0.99	12%	8.44	1.57
	25	5.19	1.02	16%	6.43	1.60	20%	7.99	2.01
De-Ice 55	15	5.10	0.92	15%	6.83	1.18	15%	8.64	1.39
	20	5.35	0.67	11%	6.98	1.03	13%	8.74	1.29
	25	5.26	0.76	13%	6.88	1.13	14%	8.11	1.92

If further studies are made regarding the application of liquid chemicals to solids, further analysis could be made to determine how much, if any, NaCl is dissolved by the liquids and is present in the residual liquid. This would require a chemical analysis of the residual. For purposes of this study, it is assumed that this amount is negligible and is the same for each liquid.

Results

Figures 7 through 21, the raw data, and test results are contained in the appendix at the end of this report.

At 15°F, little difference was seen among the different chemicals at the various pre-wetting rates. The De-Ice 55 applied at 6 gallons/ton (Figure 7) did show slightly better results than any of the other chemical/rate combinations at this temperature. At 8 gallons/ton (Figure 8), the dry NaCl sample actually performed as well as or better than the others, while De-Ice NB edged out the others at the 10 gallon/ton rate (Figure 9). Overall, the pre-wetted samples did not perform better than the dry salt at any application rate at this temperature, and the differences between the liquids were small. In fact, the trend appears to show that 6 gallons/ton is better than 10 gallons/ton overall.

Because the NaCl sample weight is constant for each test, there is less dry salt for each liquid application rate since some of the total sample weight is from the liquid pre-wetting agent. At temperatures of 15^{o} F and warmer, there is little difference between the different chemicals as far as melting ability, especially at these small pre-wet application rates. For example, the chemical with the highest specific gravity is ClearLane. At the 10 gallons/ton rate, approximately 0.2 grams (see Table 1) of liquid is present on approximately 4.1 grams NaCl in each melting test performed. Figure 5 contains the results for the melting of pure liquids at 20^{o} F. At 60 minutes, about 2.3 ml of ice is melted per gram of liquid for the ClearLane. For the 10 gallons/ton application of 0.2 grams, this is about 0.46 grams of ice melted. Figure 12 contains results for melting for dry NaCl at 20^{o} F. The melting ability at 60 minutes is 4.0 ml of ice per gram of chemical. If this is compared to the 0.2 grams of solid displaced by the pre-wetting liquid, the resultant melt would be about .8 grams of ice. This simple comparison shows that it is probably best, by weight, to use the 0.2 grams of solid NaCl, especially in a deicing mode.

An analysis of melt rates during testing showed some other helpful information. The brine amount produced at 10 minutes is a direct measure of the speed that melting starts. A look at the 10 minute data in Figure 6 shows that the AG30 starts producing brine slightly slower than the M1000 at 15^{o} F. At 20 minutes, the De-Ice 55 appears to be starting to work faster, and in fact by 30 minutes produces more brine than the others. If pre-wetting is used to “speed up” the melting action, this is an important result.

At 20°F, similar results were observed. The overall ice melting ability of all the chemicals was increased with the temperature, but no more so than with the dry salt. Once again, there was a small spread in the results seen on Figures 10, 11 and 12. No liquid chemical emerges as a clear favorite.

Finally, at 25°F, the results once again appear to be fairly even in general. The NaCl is slightly better than all of the treatments at 6 gallons/ton, De-ice 55 is the best at 8 gallons/ton, and the Corgaurd AG-30 is slightly better than the others at 10 gallons/ ton. Figures 13, 14 and 15 indicate another increase in performance with increase in temperature overall as expected.

Figures 16 through 21 illustrate the melting capacity of each chemical as a function of temperature and pre-wetting rate. Clearly, the test temperature has the greatest effect on the results. These results do show that the different chemicals my each have a specific rate that is best for performance in the 6 to 10 gallon/ton range. Figures 7, 8 and 9 are shown here for clarity, and again in the appendix.

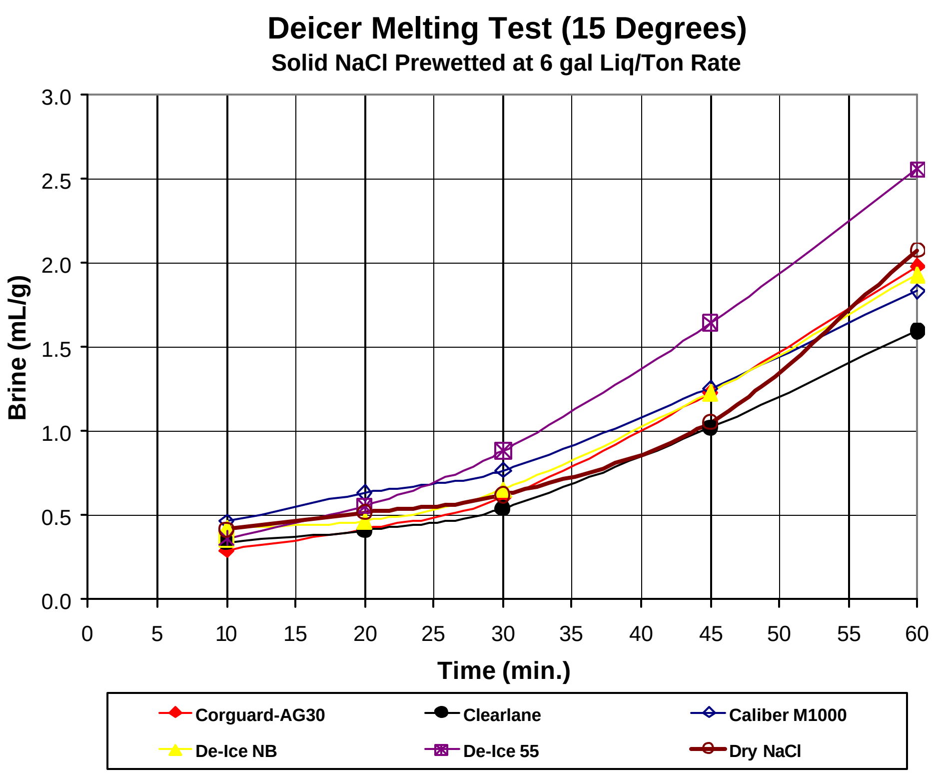

Figure 7: 15°F, 6 Gallons Liquid per Ton NaCl Pre-wetting Rate

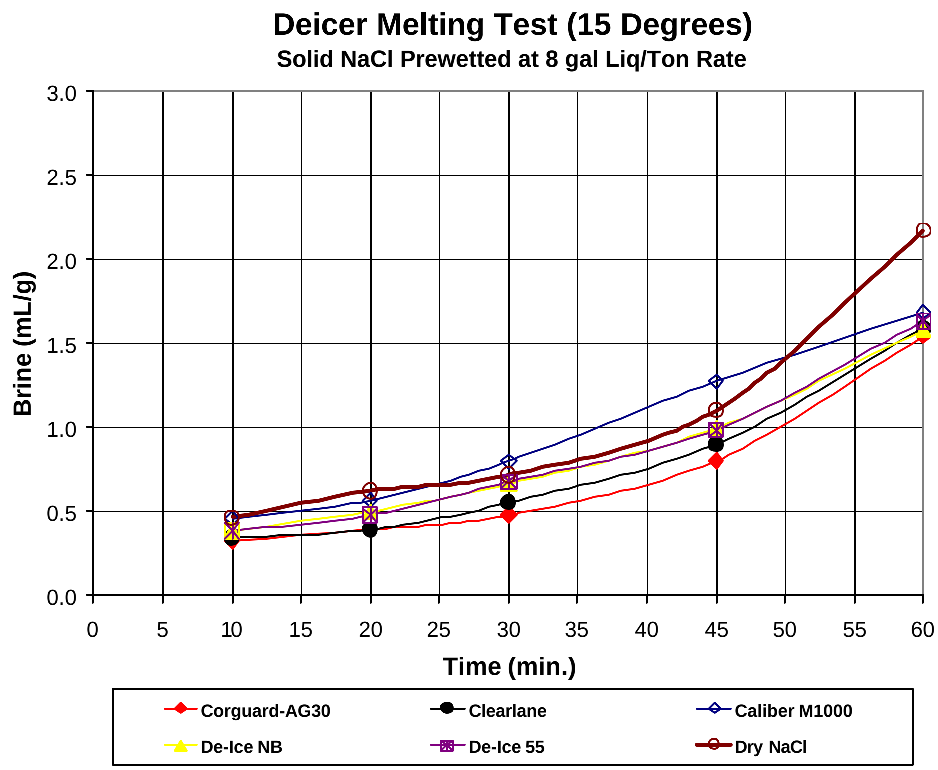

Figure 8: 15°F, 8 Gallons Liquid per Ton NaCl Pre-wetting Rate

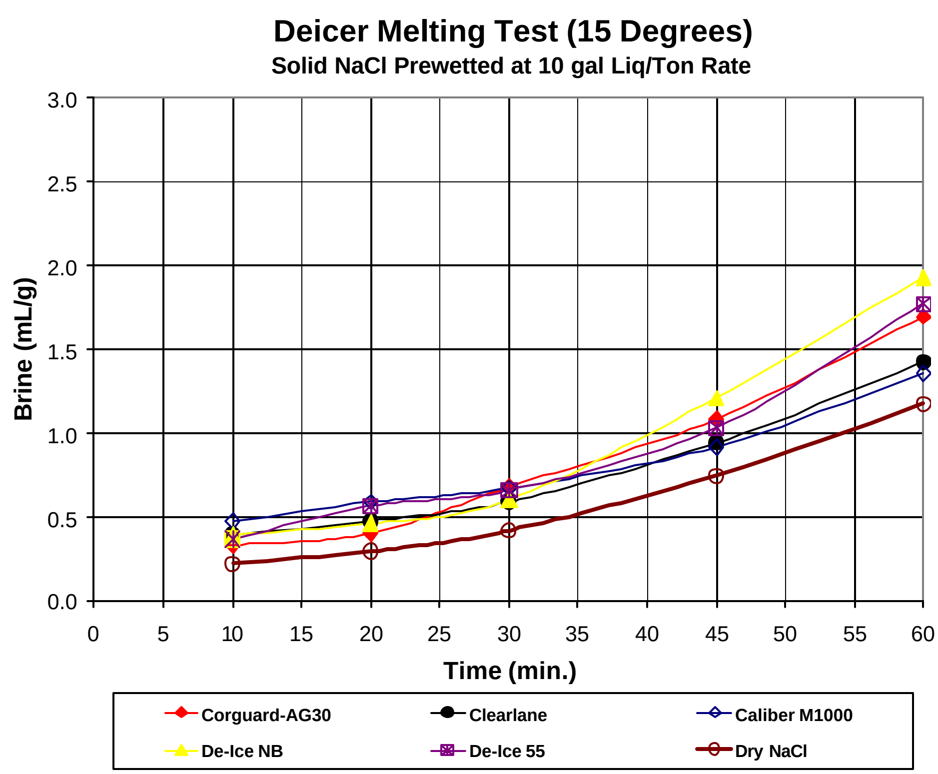

Figure 9: 15°F, 10 Gallons Liquid per Ton NaCl Pre-wetting Rate

Conclusions

A large number of tests were performed under the scope of this project. The test method parameters were determined early on by looking at particle size, liquid amount, sample size, sample preparation scenarios, and sample mixing. Since this is a laboratory test, the major emphasis was on melting performance.

Overall, little difference in ice melting ability was observed in these tests, even as compared to dry NaCl. This is consistent with the fact that only a small amount of liquid is present on each salt particle both in this controlled lab test and also in actual field application. For pure melting, a given **weight** of dry NaCl has more melting potential than an equal weight of liquid chemical. As a brine, this is not always true, however. The liquids tested here should work better at colder temperatures, but this is only relative when the small amounts applied are considered and the limited melting ability of any deicer at cold temperature is kept in mind.

Field performance factors such as clumping and adherence to road surface were not evaluated.

Some liquids were much easier to work with than others in the laboratory environment. Caliber M1000 seemed to have the best handling characteristics, both as a liquid and when used to pre-wet dry NaCl, with no foaming, very little settling, and the least residue left in the sample bottles. Corguard AG30 and ClearLane both exhibited a great deal of foaming when used as liquids, but much less when used to pre-wet the NaCl. In the field, the foaming of these two chemicals may or may not present difficulties in mixing and spray equipment. These liquids also showed a tendency to coat the NaCl somewhat unevenly, which may have contributed to relatively high residue levels. Extreme foaming was seen with De-Ice 55, which could easily lead to problems with spray equipment. Otherwise, the chemical performed well and appeared to coat the NaCl crystals evenly, with little pooling of chemical. Finally, the De-Ice NB exhibited extreme foaming, with a tendency to remain foamy after a considerable amount of time had passed. This problem should be examined further before this chemical is used on a large scale in spray equipment.

Final conclusions from this testing are that there is no benefit in increasing the amount of liquid added to salt piles from 6 to 10 gallons per ton. This is purely from a standpoint of increased melting ability by weight, however, and doesn't take into account other properties such as clumping, ease of application, and other field related items. In general, the solid rock salt and even the 23% NaCl brine test shown in Figure 6 are good melters at the temperature ranges tested.

Recommendations

Further analysis of the data from a statistical viewpoint could be performed to see if trends in the data can be further defined. This could be done relatively easily with the present data, but is beyond the scope of this first study. It may be best, however, if such an analysis is to be performed, that a larger number of data points are obtained by running mare than 3 melting tests per chemical scenario.

Controlled field testing of several scenarios would also help to quantify the performance of wetted solids.

Chemical analysis of samples taken from sprayed piles around the state would help to determine present “in the field” mixes.

Appendix

Test Data and Graphs

Tables 3 – 11

Figures 7 - 21

Table 3: 6 Gallons per Ton Application Rate, 15°F

Corguard-AG30	15 Degrees				
Deicer Weight(g)	4.2919	4.2859	4.2793	4.286	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.4	1	1.4	1.27	0.30
20	2.5	1.1	1.8	1.80	0.42
30	4	1.2	2.6	2.60	0.61
45	8.4	2.6	4.8	5.27	1.23
60	10	6.6	8.9	8.50	1.98

ClearLane	15 Degrees				
Deicer Weight(g)	4.289	4.2834	4.3077	4.293	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.4	1.4	1.6	1.47	0.34
20	1.5	2.2	1.6	1.77	0.41
30	2.4	2.4	2.2	2.33	0.54
45	3.8	3.6	5.8	4.40	1.02
60	6.6	6.4	7.6	6.87	1.60

Caliber M1000	15 Degrees				
Deicer Weight(g)	4.2876	4.2861	4.2914	4.288	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.7	2.1	2.2	2.00	0.47
20	2.6	3	2.6	2.73	0.64
30	3.8	3.1	3	3.30	0.77
45	7	5.4	3.8	5.40	1.26
60	12	7	4.6	7.87	1.83

De-Ice NB	15 Degrees				
Deicer Weight(g)	4.2619	4.2762	4.291	4.276	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.6	2	1.9	1.83	0.43
20	1.6	2	2.4	2.00	0.47
30	2.8	2.8	2.8	2.80	0.65
45	5	5.8	5	5.27	1.23
60	7.3	8.6	8.9	8.27	1.93

De-Ice 55	15 Degrees				
Deicer Weight(g)	4.2937	4.2881	4.3184	4.300	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.4	1.6	1.7	1.57	0.36
20	2.4	2.6	2.2	2.40	0.56
30	5	3.8	2.6	3.80	0.88
45	8.2	8.4	4.6	7.07	1.64
60	13	13	7	11.00	2.56

Dry NaCl	15 Degrees				
Deicer Weight(g)	4.1727	4.1715	4.1725	4.172	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.6	1.7	1.9	1.73	0.42
20	2.1	2	2.4	2.17	0.52
30	2.4	3	2.4	2.60	0.62
45	4	4.2	5	4.40	1.05
60	7.8	9	9.2	8.67	2.08

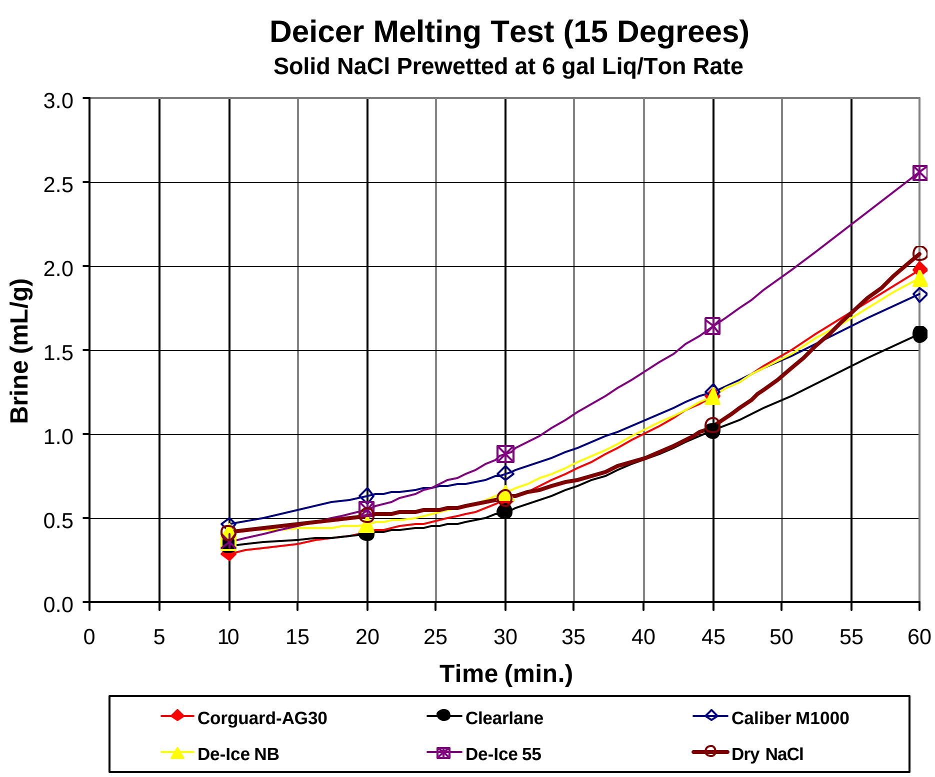

Figure 7: 15°F, 6 Gallons Liquid per Ton NaCl Results

Table 4: 8 Gallons/Ton Application Rate, 15°F

Corguard-AG30	15 Degrees				
Deicer Weight(g)	4.3205	4.3136	4.3252	4.320	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.2	1.4	1.6	1.40	0.32
20	1.2	2	1.9	1.70	0.39
30	2.2	2.2	1.8	2.07	0.48
45	3.8	3.4	3.2	3.47	0.80
60	8.2	6	5.8	6.67	1.54

ClearLane	15 Degrees				
Deicer Weight(g)	4.3079	4.3461	4.3487	4.334	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.4	1.6	1.5	1.50	0.35
20	1.6	1.9	1.6	1.70	0.39
30	2.4	2.6	2.2	2.40	0.55
45	3	4.7	4	3.90	0.90
60	6.9	9.4	4.4	6.90	1.59

Caliber M1000	15 Degrees				
Deicer Weight(g)	4.3428	4.3279	4.3652	4.345	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.8	2.2	2	2.00	0.46
20	2.2	3	2.2	2.47	0.57
30	4.2	3.4	2.8	3.47	0.80
45	7.2	5.4	4	5.53	1.27
60	10	6.4	5.6	7.33	1.69

De-Ice NB	15 Degrees				
Deicer Weight(g)	4.3182	4.312	4.3417	4.324	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.4	1.6	2	1.67	0.39
20	1.8	2.1	2.6	2.17	0.50
30	3	2.2	3.4	2.87	0.66
45	5.8	2.2	4.9	4.30	0.99
60	7.7	6	6.8	6.83	1.58

De-Ice 55	15 Degrees				
Deicer Weight(g)	4.3202	4.3274	4.3373	4.328	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.6	1.8	1.6	1.67	0.39
20	1.8	2.4	2	2.07	0.48
30	2.6	3.8	2.4	2.93	0.68
45	3.2	5.7	3.9	4.27	0.99
60	5.2	7.8	8.2	7.07	1.63

Dry NaCl	15 Degrees				
Deicer Weight(g)	4.1662	4.1832	4.1785	4.176	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.9	1.7	2.2	1.93	0.46
20	2.6	2	3.2	2.60	0.62
30	3	2.2	3.8	3.00	0.72
45	5	3.2	5.6	4.60	1.10
60	9.4	8.4	9.4	9.07	2.17

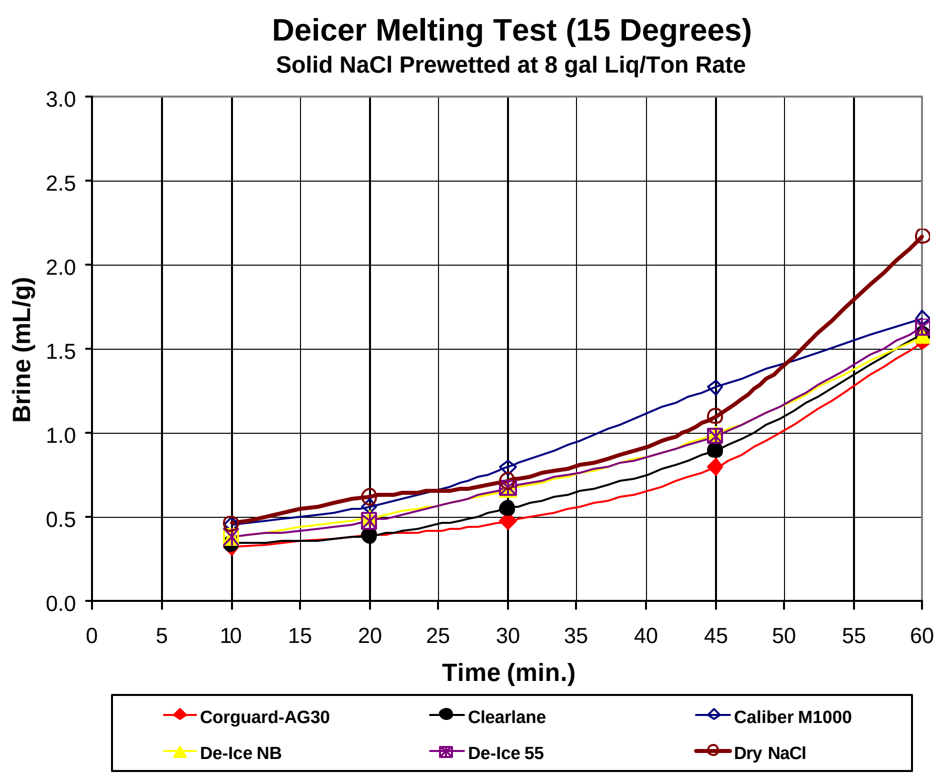

Figure 8: 15°F, 8 Gallons Liquid per Ton NaCl Results

Table 5: 10 Gallons/Ton Application Rate, 15°F

Corguard-AG30	15 Degrees				
Deicer Weight(g)	4.3464	4.331	4.3591	4.346	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.4	1.1	1.8	1.43	0.33
20	1.6	1.3	2.3	1.73	0.40
30	3	2	3.8	2.93	0.68
45	3.7	3.5	6.9	4.70	1.08
60	6.2	6.9	9	7.37	1.70

ClearLane	15 Degrees				
Deicer Weight(g)	4.3617	4.3643	4.3632	4.363	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.4	1.7	2	1.70	0.39
20	2	1.6	2.6	2.07	0.47
30	2	2.2	3.5	2.57	0.59
45	3.4	3.5	5.4	4.10	0.94
60	6	5.6	7	6.20	1.42

Caliber M1000	15 Degrees				
Deicer Weight(g)	4.378	4.3737	4.3751	4.376	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2	2	2.2	2.07	0.47
20	2.6	2.4	2.7	2.57	0.59
30	2.7	3.1	3	2.93	0.67
45	4.2	3.8	4	4.00	0.91
60	6.6	5.2	6	5.93	1.36

De-Ice NB	15 Degrees				
Deicer Weight(g)	4.3594	4.3508	4.3574	4.356	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.7	1.6	1.8	1.70	0.39
20	2	2.2	1.8	2.00	0.46
30	2.6	2.4	2.8	2.60	0.60
45	6.8	4	5	5.27	1.21
60	14	5.8	5.4	8.40	1.93

De-Ice 55	15 Degrees				
Deicer Weight(g)	4.3718	4.3743	4.3693	4.372	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.4	1.4	2	1.60	0.37
20	2.2	2	3.2	2.47	0.56
30	2.4	2	4.2	2.87	0.66
45	3.5	3	7	4.50	1.03
60	6.2	8	9	7.73	1.77

Dry NaCl	15 Degrees				
Deicer Weight(g)	4.1748	4.1782	15.5619	7.972	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.6	1.6	2	1.73	0.22
20	2.2	2.4	2.4	2.33	0.29
30	4	2.6	3.4	3.33	0.42
45	7.4	4.8	5.6	5.93	0.74
60	12	5.8	10.2	9.33	1.17

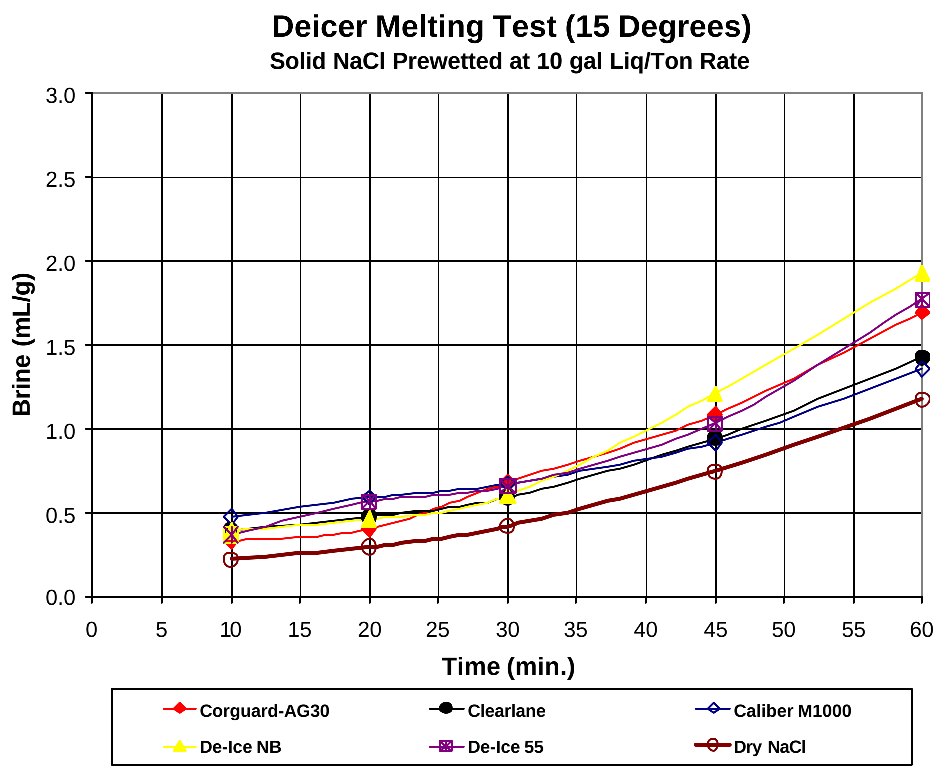

Figure 9: 15°F, 10 Gallons Liquid per Ton NaCl Results

Table 6: 6 Gallons/Ton Application Rate, 20°F

Corguard-AG30	20 Degrees				
Deicer Weight(g)	4.291	4.2907	4.302	4.295	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	1.8	2.2	2.1	2.03	0.47
20	3	2.4	2.8	2.73	0.64
30	6.2	4.8	5.4	5.47	1.27
45	13	10.2	9	10.73	2.50
60	16	17	10.5	14.50	3.38

ClearLane	20 Degrees				
Deicer Weight(g)	4.2971	4.2942	4.3006	4.297	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.8	2.2	2	2.33	0.54
20	4.2	3.1	2.2	3.17	0.74
30	6.2	5.2	2.6	4.67	1.09
45	12	10.1	8	10.03	2.33
60	16.5	15.5	10	14.00	3.26

Caliber M1000	20 Degrees				
Deicer Weight(g)	4.2957	4.3085	4.2922	4.299	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.6	2.4	2.6	2.53	0.59
20	3.2	3.3	4	3.50	0.81
30	5.8	7.2	5	6.00	1.40
45	12	11	10.5	11.17	2.60
60	17	16.5	14.5	16.00	3.72

De-Ice NB	20 Degrees				
Deicer Weight(g)	4.2824	4.2855	4.2947	4.288	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.2	2.8	2	2.33	0.54
20	3.9	4.7	2.2	3.60	0.84
30	6.7	9.2	3.7	6.53	1.52
45	14	16	10	13.33	3.11
60	15	19	12.8	15.60	3.64

De-Ice 55	20 Degrees				
Deicer Weight(g)	4.2921	4.2917	4.3092	4.298	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.4	2.4	2.6	2.47	0.57
20	3.2	3.8	3.2	3.40	0.79
30	6.2	6.6	4.2	5.67	1.32
45	12.5	11	10	11.17	2.60
60	18	18	14.5	16.83	3.92

Dry NaCl	20 Degrees				
Deicer Weight(g)	4.1724	4.1849	4.1829	4.180	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.2	2.4	2.4	2.33	0.56
20	3	3.8	2.8	3.20	0.77
30	4.7	5.2	4	4.63	1.11
45	9.5	11.8	8.7	10.00	2.39
60	15	16	12	14.33	3.43

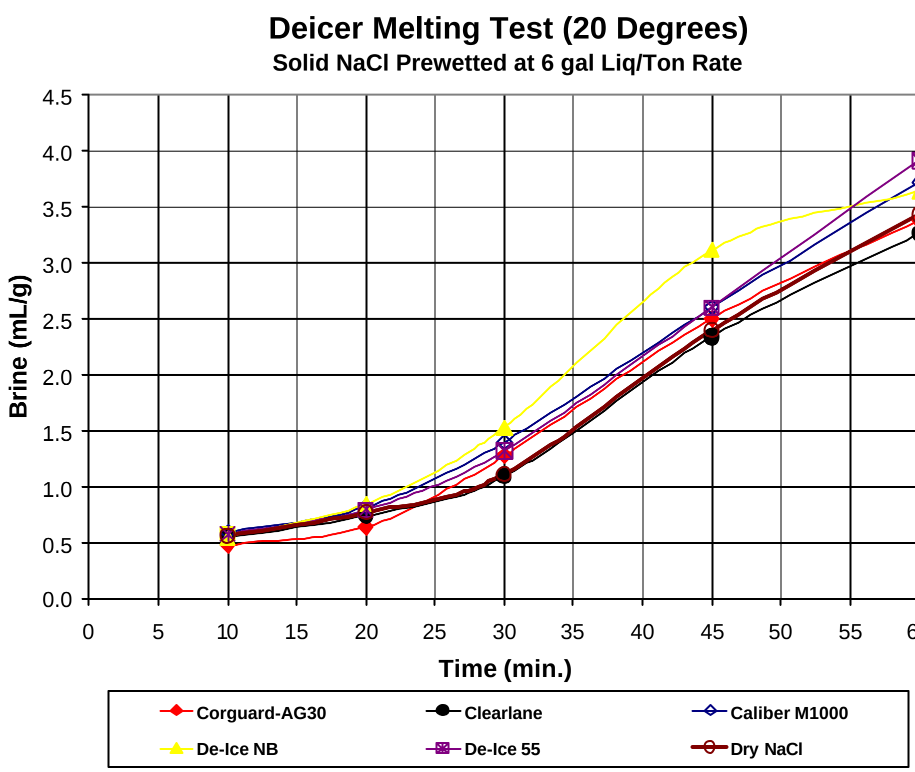

Figure 10: 20°F, 6 Gallons Liquid per Ton NaCl Results

Table 7: 8 Gallons/Ton Application Rate, 20°F

Corguard-AG30	20 Degrees				
Deicer Weight(g)	4.3215	4.2989	4.32	4.313	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2	2	1.6	1.87	0.43
20	2.6	2.2	2.2	2.33	0.54
30	5.4	3.4	3.6	4.13	0.96
45	10	8.6	8	8.87	2.06
60	14	13.5	15	14.17	3.28

ClearLane	20 Degrees				
Deicer Weight(g)	4.3305	4.3285	4.3344	4.331	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.4	2.2	2.6	2.40	0.55
20	3.4	2.6	2.8	2.93	0.68
30	5	2.4	6.2	4.53	1.05
45	12.8	6	12	10.27	2.37
60	17.5	12	17	15.50	3.58

Caliber M1000	20 Degrees				
Deicer Weight(g)	4.3417	4.3316	4.3464	4.340	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.2	3	2.8	3.00	0.69
20	3.6	3.6	4	3.73	0.86
30	4.7	6.6	4.6	5.30	1.22
45	9	14	9.5	10.83	2.50
60	12	17.5	18.5	16.00	3.69

De-Ice NB	20 Degrees				
Deicer Weight(g)	4.3442	4.3273	4.322	4.331	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.4	2	2.8	2.40	0.55
20	3	2.8	4	3.27	0.75
30	5.4	6.2	5.4	5.67	1.31
45	11	12.5	13	12.17	2.81
60	15.5	16	17	16.17	3.73

De-Ice 55	20 Degrees				
Deicer Weight(g)	4.3564	4.3274	4.3191	4.334	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.5	2.8	2.2	2.50	0.58
20	2.9	3.2	2.6	2.90	0.67
30	4.6	4.6	5	4.73	1.09
45	8	8.6	10.5	9.03	2.08
60	14.5	13.5	15	14.33	3.31

Dry NaCl	20 Degrees				
Deicer Weight(g)	4.1751	4.1763	4.1741	4.175	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.4	2.8	2.6	2.60	0.62
20	3.8	4.4	4.2	4.13	0.99
30	5.5	5.8	6.6	5.97	1.43
45	8.5	12.5	13	11.33	2.71
60	14.2	17.5	17	16.23	3.89

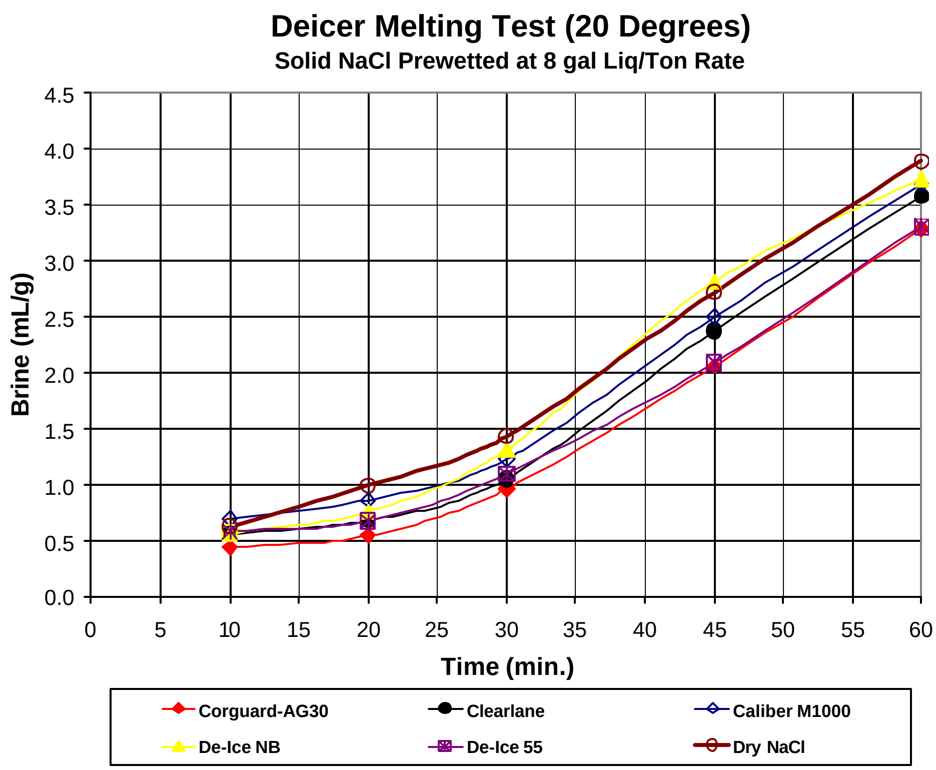

Figure 11: 20°F, 8 Gallons Liquid per Ton NaCl Results

Table 8: 10 Gallons/Ton Application Rate, 20°F

Corguard-AG30	20 Degrees				
Deicer Weight(g)	4.3394	4.3473	4.3607	4.349	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.2	2	2	2.07	0.48
20	2.6	2.6	3	2.73	0.63
30	3.6	3.8	4.8	4.07	0.94
45	10	6	9.5	8.50	1.95
60	11.5	13.5	16	13.67	3.14

ClearLane	20 Degrees				
Deicer Weight(g)	4.3666	4.3593	4.3615	4.362	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.6	2.2	2.6	2.47	0.57
20	3	2.8	3.2	3.00	0.69
30	4	5.9	5.4	5.10	1.17
45	7	10	10.5	9.17	2.10
60	14.8	20.5	18.5	17.93	4.11

Caliber M1000	20 Degrees				
Deicer Weight(g)	4.3756	4.3845	4.3815	4.381	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.5	3	3	2.83	0.65
20	3	3.5	3	3.17	0.72
30	4.8	6.2	5.4	5.47	1.25
45	7.2	11.2	11	9.80	2.24
60	11.8	16	15	14.27	3.26

De-Ice NB	20 Degrees				
Deicer Weight(g)	4.358	4.3488	4.3643	4.357	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.5	2.2	2.4	2.37	0.54
20	3.3	3.3	3.6	3.40	0.78
30	4.4	5.7	6.2	5.43	1.25
45	8.5	10	10	9.50	2.18
60	12	18	15.5	15.17	3.48

De-Ice 55	20 Degrees				
Deicer Weight(g)	4.3753	4.3716	4.3833	4.377	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.6	2.6	2.6	2.60	0.59
20	3.4	3.6	3.4	3.47	0.79
30	4.8	7	5.4	5.73	1.31
45	10	11.2	10.5	10.57	2.41
60	16	17.5	16	16.50	3.77

Dry NaCl	20 Degrees				
Deicer Weight(g)	4.1744	4.1838	4.1666	4.175	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.8	2.9	2.6	2.77	0.66
20	3.2	4	3.4	3.53	0.85
30	5.5	6.6	7.7	6.60	1.58
45	11	12	13	12.00	2.87
60	17	15	18.5	16.83	4.03

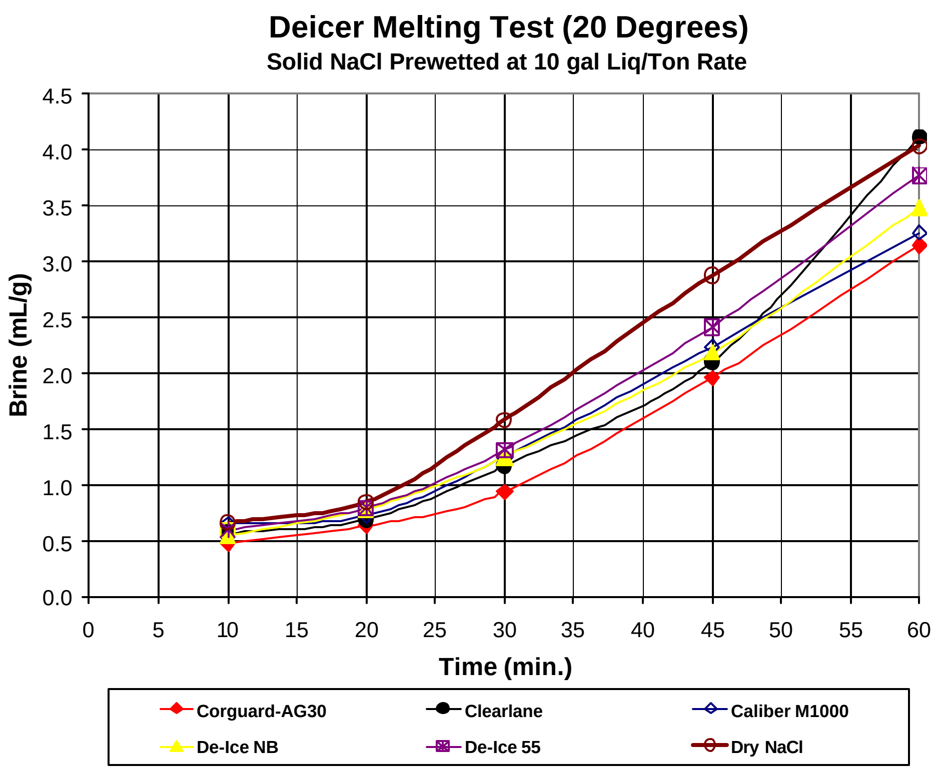

Figure 12: 20°F, 10 Gallons Liquid per Ton NaCl Results

Table 9: 6 Gallons/Ton Application Rate, 25°F

Corguard-AG30	25 Degrees				
Deicer Weight(g)	4.2771	4.2768	4.293	4.282	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.6	3	2.9	2.83	0.66
20	3.6	7	5.4	5.33	1.25
30	10.3	13.8	10.8	11.63	2.72
45	14	20	19	17.67	4.13
60	26	28	28	27.33	6.38

ClearLane	25 Degrees				
Deicer Weight(g)	4.2751	4.2771	4.2934	4.282	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.2	3.8	3.6	3.53	0.83
20	6	7.8	4.8	6.20	1.45
30	10	14	9.2	11.07	2.58
45	22.5	24.5	21	22.67	5.29
60	29	29	29	29.00	6.77

Caliber M1000	25 Degrees				
Deicer Weight(g)	4.3295	4.304	4.3037	4.312	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.8	3.8	3.4	3.67	0.85
20	5.8	6	5.1	5.63	1.31
30	10.7	12	10	10.90	2.53
45	19	20.5	23	20.83	4.83
60	28	28	27.5	27.83	6.45

De-Ice NB	25 Degrees				
Deicer Weight(g)	4.2776	4.2853	4.2866	4.283	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.9	3.6	2.6	3.03	0.71
20	3.2	6.1	4.7	4.67	1.09
30	8.2	13.5	11	10.90	2.54
45	19.5	23	21	21.17	4.94
60	29.5	28.5	26	28.00	6.54

De-Ice 55	25 Degrees				
Deicer Weight(g)	4.3029	4.2942	4.2854	4.294	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.8	2.4	2.8	3.00	0.70
20	5.5	5.7	5.6	5.60	1.30
30	12	12	12	12.00	2.79
45	19.5	20	18	19.17	4.46
60	25	31.5	31	29.17	6.79

Dry NaCl	25 Degrees				
Deicer Weight(g)	4.1674	4.1843	4.181	4.178	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.7	3.8	3.8	3.77	0.90
20	7.6	6.2	8.8	7.53	1.80
30	13	13.5	16.5	14.33	3.43
45	24	20.5	23.5	22.67	5.43
60	30.5	27.5	29	29.00	6.94

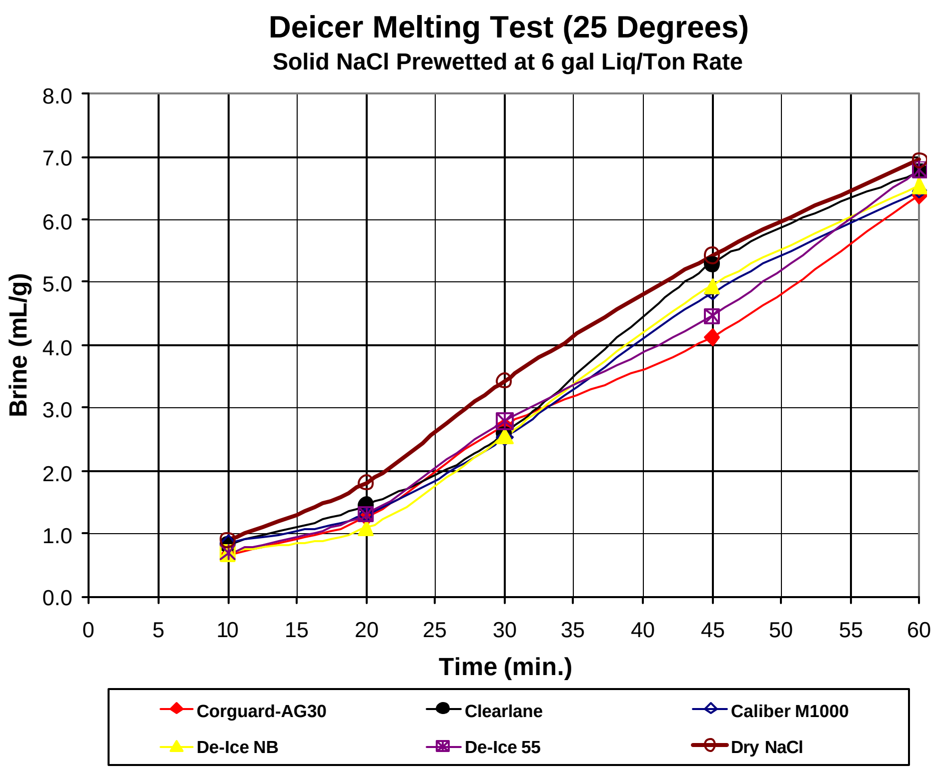

Figure 13: 25°F, 6 Gallons Liquid per Ton NaCl Results

Table 10: 8 Gallons/Ton Application Rate, 25°F

Corguard-AG30	25 Degrees				
Deicer Weight(g)	4.3254	4.3151	4.3151	4.319	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.7	2.6	3	2.77	0.64
20	5.6	3.8	6.2	5.20	1.20
30	12	8.5	15	11.83	2.74
45	21.8	22	21	21.60	5.00
60	30	29	28	29.00	6.72

ClearLane	25 Degrees				
Deicer Weight(g)	4.3407	4.3267	4.3393	4.336	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.9	3	3	2.97	0.68
20	3.6	4.9	4.4	4.30	0.99
30	9.2	7.5	10	8.90	2.05
45	20	14.5	23.5	19.33	4.46
60	32	23	26	27.00	6.23

Caliber M1000	25 Degrees				
Deicer Weight(g)	4.3408	4.3293	4.3368	4.336	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.2	3.4	3.6	3.40	0.78
20	4.8	5.9	5.4	5.37	1.24
30	10.8	12.8	9	10.87	2.51
45	21	20	15	18.67	4.31
60	24	27.5	20	23.83	5.50

De-Ice NB	25 Degrees				
Deicer Weight(g)	4.3134	4.3039	4.3081	4.308	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.4	3	2.8	3.07	0.71
20	4.6	5	3.7	4.43	1.03
30	11	8	11.5	10.17	2.36
45	21	14.5	23	19.50	4.53
60	26	23	29	26.00	6.03

De-Ice 55	25 Degrees				
Deicer Weight(g)	4.3335	4.311	4.3194	4.321	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.2	3.6	3.4	3.40	0.79
20	3.5	5.8	6	5.10	1.18
30	12	12	14.5	12.83	2.97
45	27	23.5	25.5	25.33	5.86
60	33	28.5	32	31.17	7.21

Dry NaCl	25 Degrees				
Deicer Weight(g)	4.1762	4.1644	4.1614	4.167	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.3	3.2	3.4	3.30	0.79
20	4.3	4.8	5.8	4.97	1.19
30	10.5	10.2	11	10.57	2.54
45	22	18	17.5	19.17	4.60
60	31	26.2	28	28.40	6.81

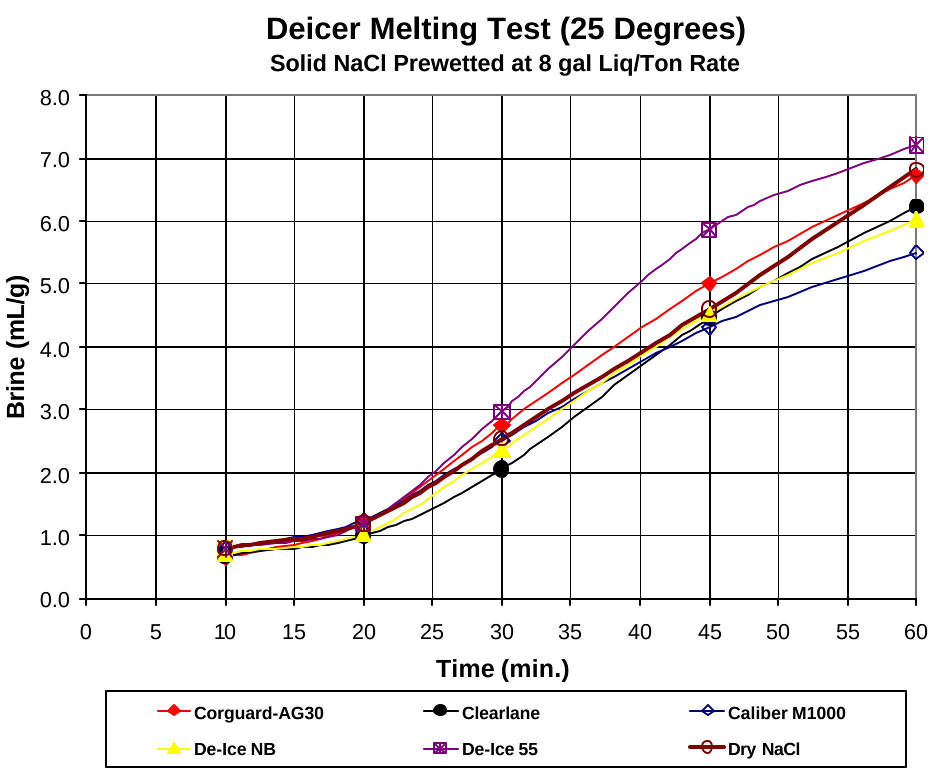

Figure 14: 25°F, 8 Gallons Liquid per Ton NaCl Results

Table 11: 10 Gallons/Ton Application Rate, 25°F

Corguard-AG30	25 Degrees				
Deicer Weight(g)	4.3492	4.3354	4.3514	4.345	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.8	3.4	3.4	3.20	0.74
20	7.7	4.8	6.2	6.23	1.43
30	15	10.5	13	12.83	2.95
45	22.5	22.5	25	23.33	5.37
60	30	28.5	31	29.83	6.87

ClearLane	25 Degrees				
Deicer Weight(g)	4.3664	4.3516	4.3581	4.359	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	2.8	3.4	3	3.07	0.70
20	3.9	4	2.8	3.57	0.82
30	11	7.5	8.7	9.07	2.08
45	17.5	19.5	23	20.00	4.59
60	27.5	29	28	28.17	6.46

Caliber M1000	25 Degrees				
Deicer Weight(g)	4.3746	4.376	4.3868	4.379	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	4	4	3.6	3.87	0.88
20	7.8	8.2	4.4	6.80	1.55
30	15	14	7.8	12.27	2.80
45	23.5	23	20	22.17	5.06
60	30.5	28	26	28.17	6.43

De-Ice NB	25 Degrees				
Deicer Weight(g)	4.3503	4.3338	4.3517	4.345	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.2	3.1	3.2	3.17	0.73
20	4.4	4.2	3.8	4.13	0.95
30	11	8	10	9.67	2.22
45	20.5	18.5	22	20.33	4.68
60	29	24	27	26.67	6.14

De-Ice 55	25 Degrees				
Deicer Weight(g)	4.3544	4.3385	4.3603	4.351	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.4	3	3.3	3.23	0.74
20	7.2	3.5	4.8	5.17	1.19
30	14	11	12.5	12.50	2.87
45	21	23	21	21.67	4.98
60	26	28	29.5	27.83	6.40

Dry NaCl	25 Degrees				
Deicer Weight(g)	4.166	4.1656	4.1727	4.168	
Time (min.)	Trial 1 (ml)	Trial 2 (ml)	Trial 3 (ml)	Ave.	ml/g
10	3.2	3	3.3	3.17	0.76
20	6	5.7	6.2	5.97	1.43
30	12	11	9.5	10.83	2.60
45	22.5	22.5	16.5	20.50	4.92
60	27	29	27.5	27.83	6.68

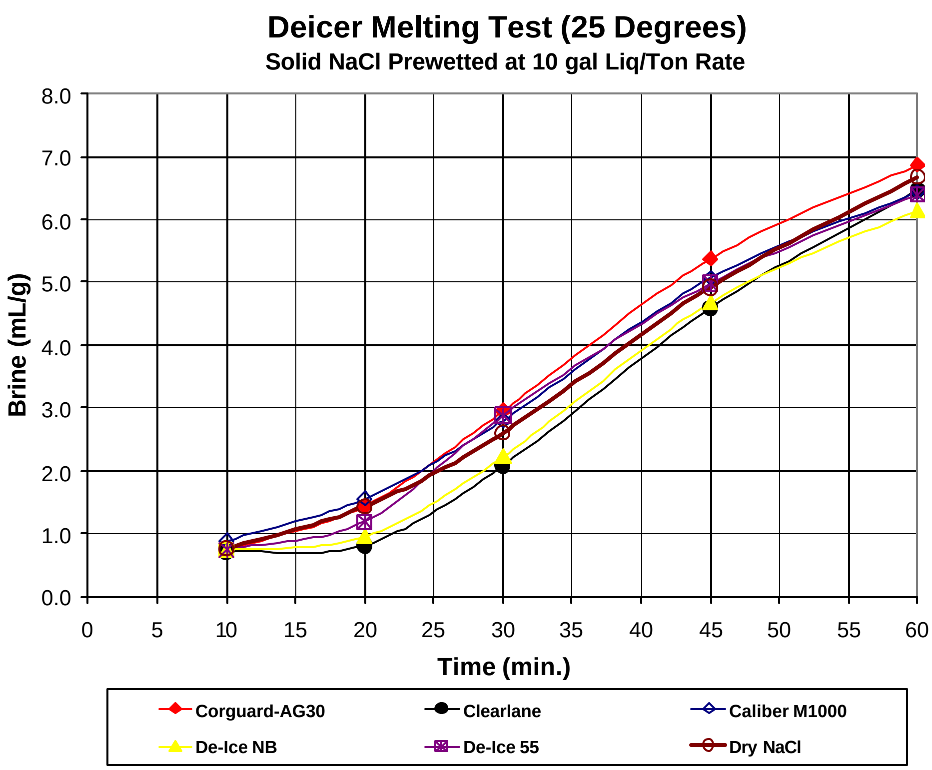

Figure 15: 25°F, 10 Gallons Liquid per Ton NaCl Results

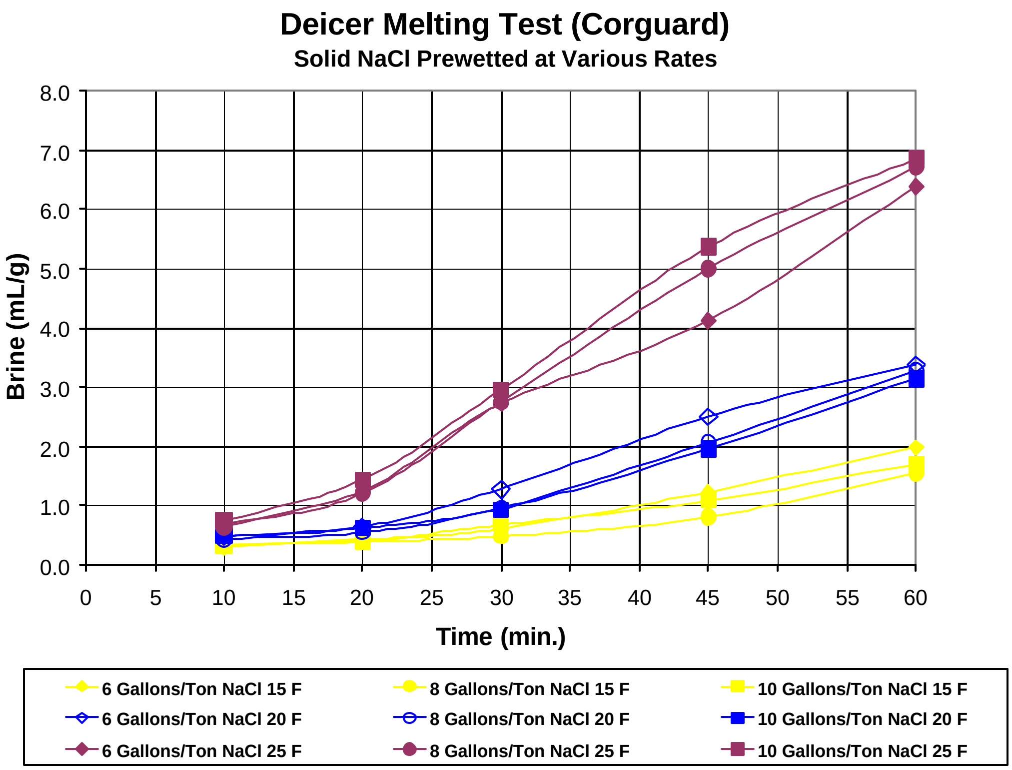

Figure 16: Corguard Melting Test Results

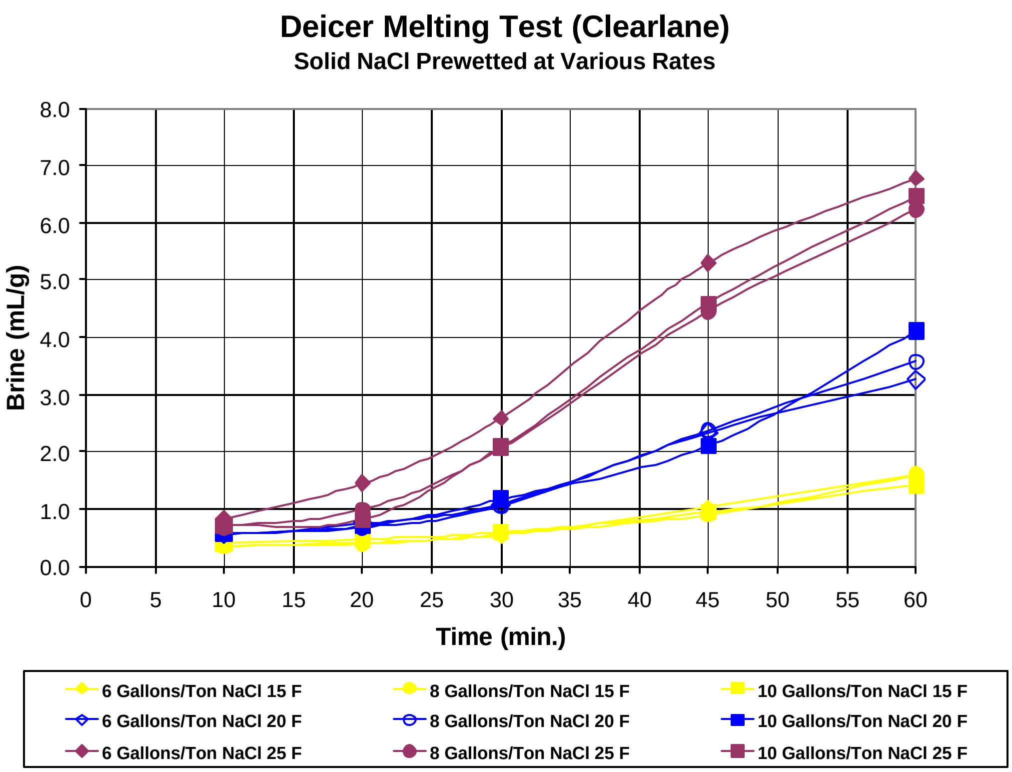

Figure 17: Clearlane Melting Test Results

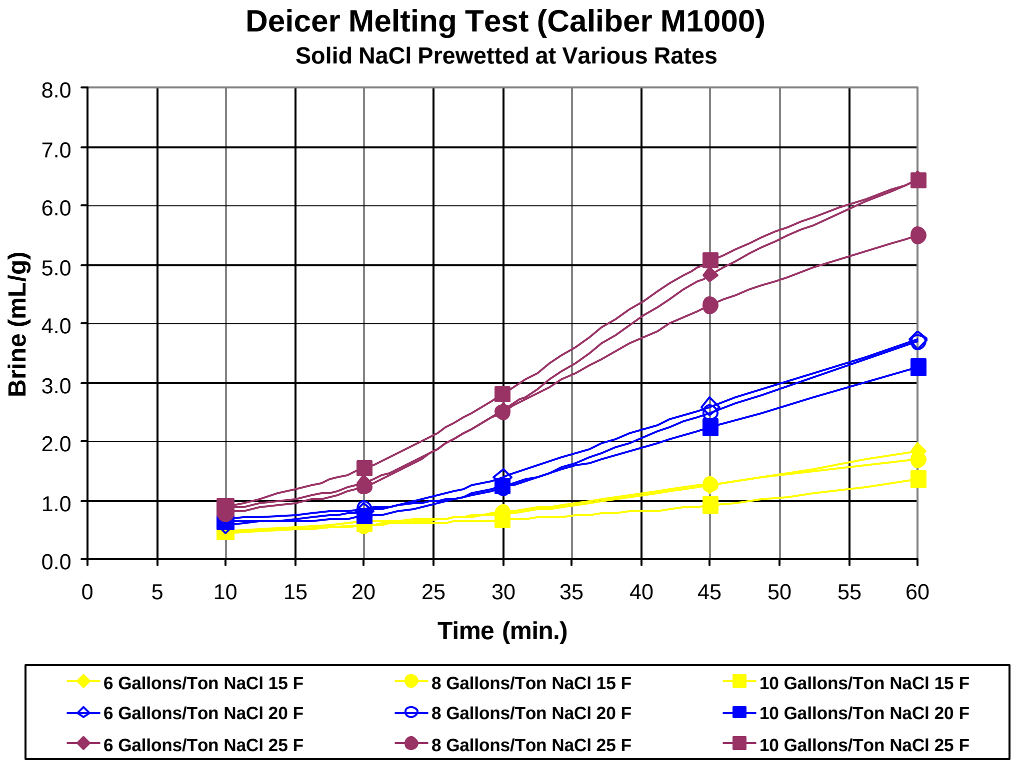

Figure 18: Caliber M1000 Melting Test Results

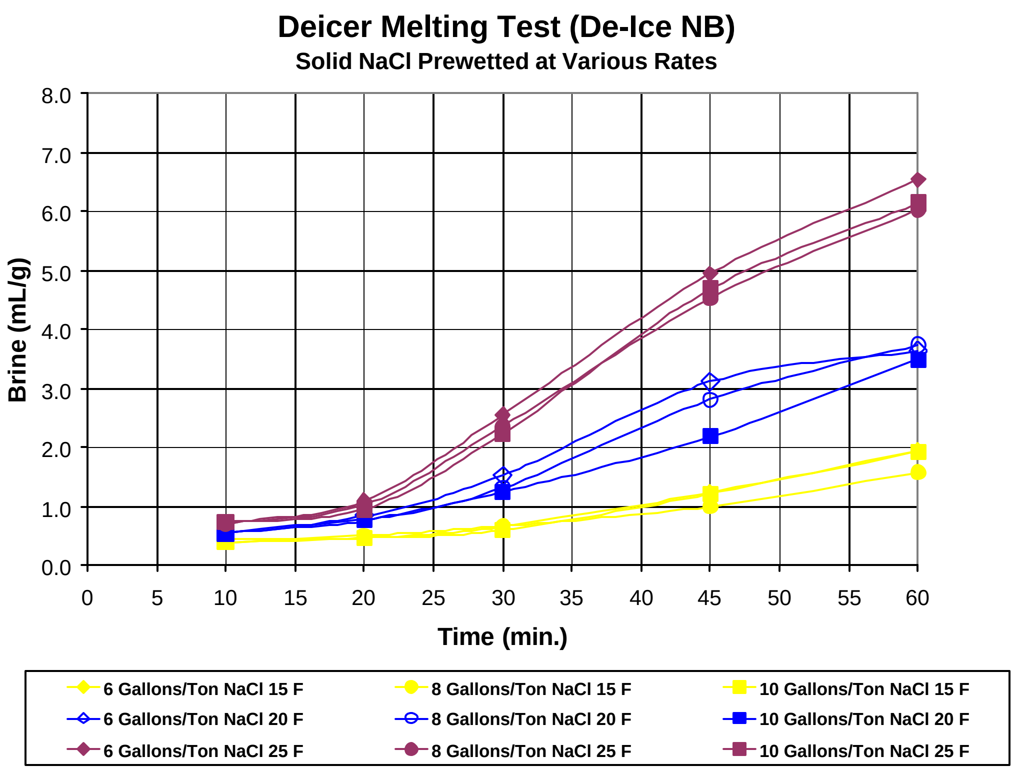

Figure 19: De-Ice NB Melting Test Results

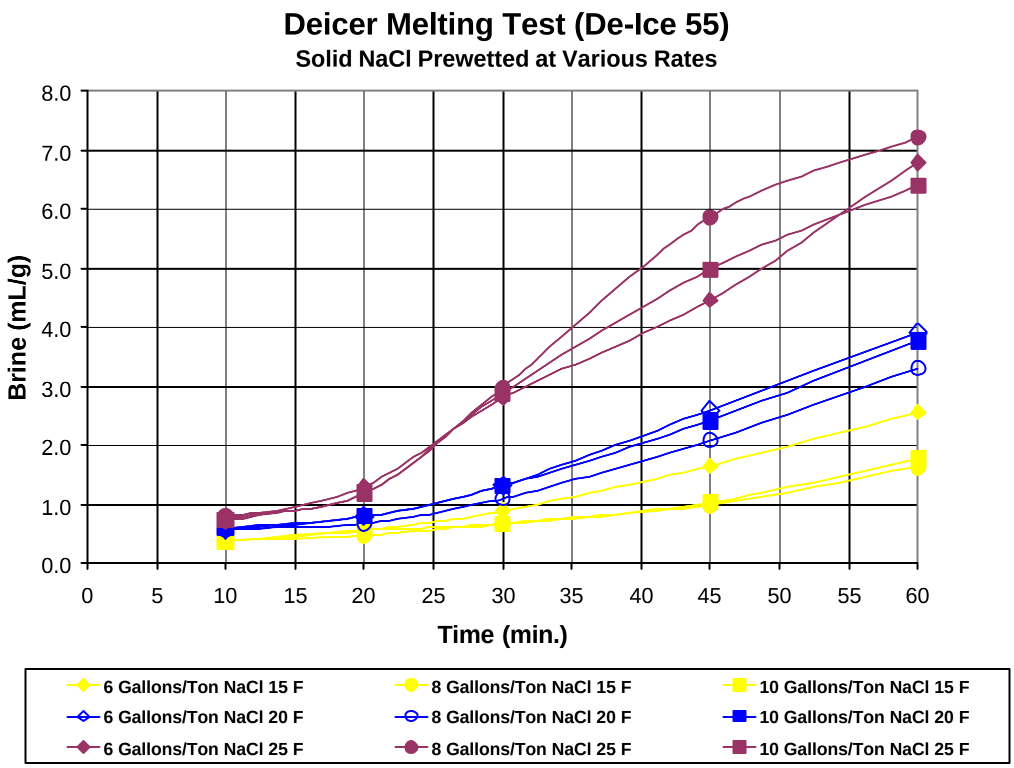

Figure 20: De-Ice 55 Melting Test Results

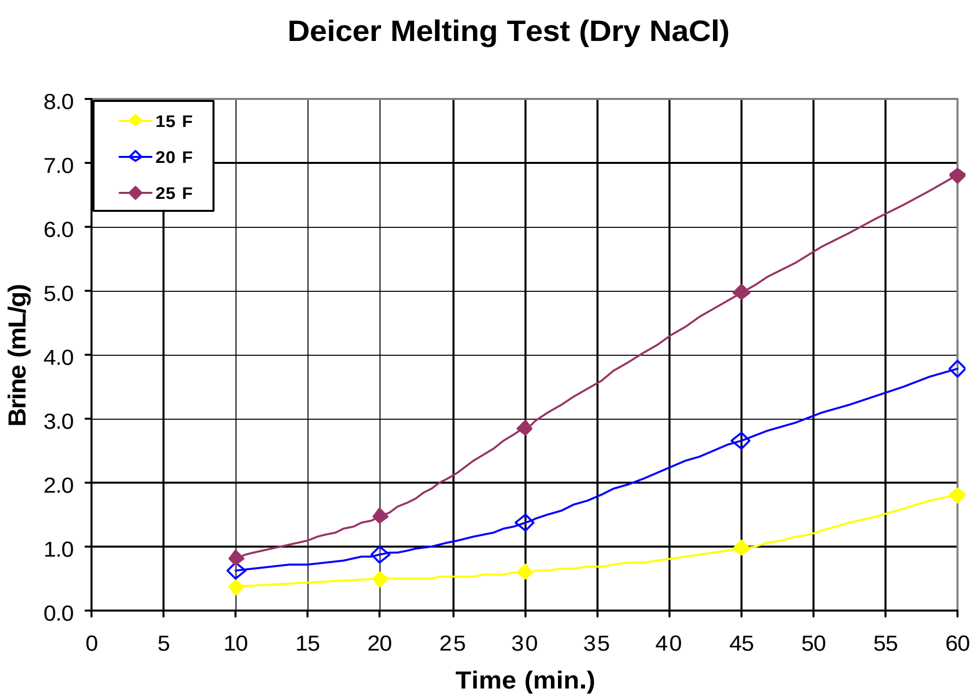

Figure 21: Dry NaCl Melting Test Results